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ABSTRACT

Undergraduate students often leave statistics courses not fully understanding how to apply statistical concepts (M. Bonsangue, 1994). In order to enhance student learning and improve the understanding and application of statistical concepts, an elementary statistics course was transformed from a lecture-based course into one that integrates technology with active and collaborative learning methods. The redesigned course is more student-centered than instructor-centered. Students have one session each week in a large group meeting, and two sessions in a computer laboratory. The organizing center for the new course is a Web site developed by the institutions Center for Academic Computing. The effect of these changes was evaluated using a combination of pre- and postcontent knowledge tests for 340 students in the traditional format and 140 in the new design. The overall result of these changes shows that student performance on the content test was higher in the redesigned classes than in the traditional course. (Contains 4 tables, 4 figures, and 18 references.) (SLD)

Transforming Elementary Statistics to Enhance Student Learning

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Abstract

Undergraduate students often leave statistics courses not fully understanding how to apply statistical concepts (Bonsangue, 1994). In order to enhance student learning and improve the understanding and application of statistical concepts, an elementary statistics course was transformed from a lecture-based course into one that integrates technology with active and collaborative learning methods. The effect of these changes was evaluated using a combination of pre- and post-content knowledge tests. The overall results of these changes showed that student performance on the content test was higher in the redesigned classes compared to the traditional course.

Statistics is predominantly viewed by students as a course filled with abstract concepts and memorization of facts and formulas. Traditionally, it has been taught using lectures where conceptual information is transmitted to students in a large lecture hall with little or no opportunity for discussion of those concepts. Faculty members in these types of courses are commonly referred to as the "sage on the stage" and students typically sit passively in their seats and take notes. While this could be considered an efficient method of teaching to a large number of students (Schaeffer et. al., 2001), it does little to enhance student learning (Boyer Commission, 1998). As a result, students often leave the course still not fully understanding how to apply statistical concepts in both life and in subsequent courses where an introductory statistics course is a prerequisite. In this paper, we will describe the transformation of elementary statistics (Stat 200) at Penn State's University Park campus from a lecture-based course similar to the one described above into a course that effectively integrates technology with active and collaborative learning methods.

The Traditional Course

Elementary Statistics in its traditional form was a lecture-based course taught in the fall, spring, and summer semesters to approximately 2,200 students annually. During the fall and spring semesters, each of the four lecture sections enrolled 240 students who were taught by full-time faculty. Twelve graduate teaching assistants each taught two recitation sections[1] per week that had an average enrollment of 40 students. In the traditional model, each lecture section met three times per week and each recitation section met twice a week. The students enrolled in the course were predominantly freshmen and sophomores from the fields of education, communications, health and human development, and the liberal arts. These students were required to take the course as part of their major. Additionally, since the course fulfills a general education requirement at Penn State, other students at the university who needed credits in quantification also took it.

Faculty members teaching Stat 200 often complained that due to the large class size there was little opportunity for student-to-faculty or student-to-student interaction. As a result, students rarely applied course principles and concepts in a meaningful way (Cross, 1987; Chickering & Gamson, 1987). The only opportunity for interaction took place in the recitation meetings and when these interactions occurred, they were minimal at best. In these recitation meetings, teaching assistants would primarily review

[1] Classes containing a subset of students from a large lecture section.

homework problems and administer quizzes. While this traditional course delivery model seemed to work because of the learning style of a few of the students, the majority of the students finished the course with only a cursory understanding of the basic statistical concepts (Miller, Groccia, & Wilkes, 1996). Something had to change.

The Redesigned Course

In 1998, the faculty members who taught Stat 200 approached Penn State's Schreyer Institute for Innovation in Learning and the Center for Academic Computing in search of ways to improve student learning in the course. Specifically, they were looking to find a way to solve five specific academic problems: 1) The traditional format did not address the broad range of quantitative skills possessed by students in the course; 2) the original course format did not provide students with opportunities for hands-on experience analyzing and collecting data; 3) it was difficult to find qualified graduate teaching assistants to teach the recitation sections since most of the graduate students in the department had undergraduate degrees in other scientific disciplines; 4) the course did not provide opportunities for individual tutoring of students since office hour availability was limited; and 5) the current course structure allowed little opportunity for interactions between students and faculty. After several consultations between instructional designers and the faculty members, it became clear that in order to solve these perceived problems a solution was needed that would not only restructure the way the course was taught, but also incorporate alternative teaching and learning methods.

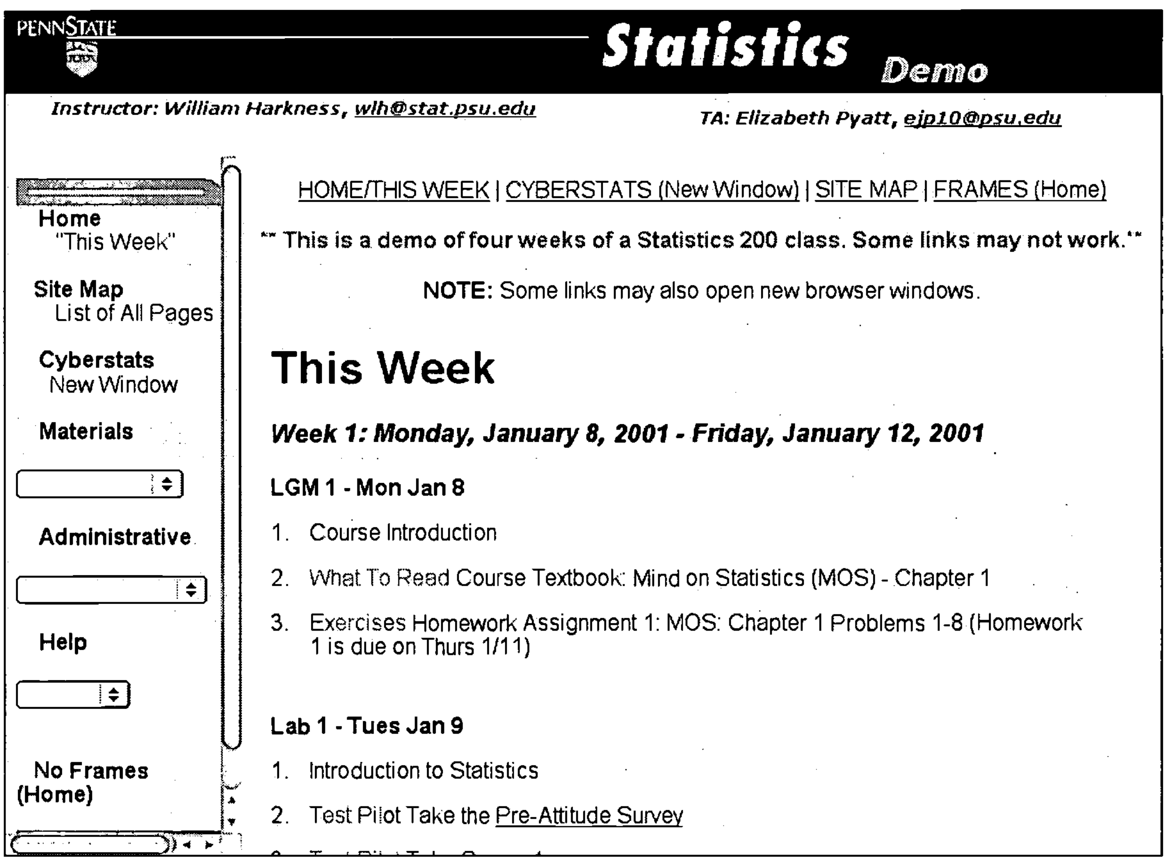
In the spring of 1999, the first author of this paper proposed a new delivery model for the course. The goals for the redesigned course were to increase students' ability to understand and apply basic concepts of statistics, to actively participate in data analysis and design, to critically evaluate reports containing statistical analyses of surveys and experiments, to actively engage with course materials and other students, and to provide more opportunity for one-to-one interaction with faculty. The new model not only addressed these goals, but also capitalized on available technology as a means of giving students the opportunity to apply statistical concepts (Chrisman & Harvey, 1998). The redesigned model was proposed to and ultimately received implementation support from the Center for Academic Transformation's Learning and Technology Program, sponsored by the Pew Charitable Trusts.

The new model allows for a more student-centered rather than instructor-centered classroom. Students spend one session per week in a large group meeting (lecture with an enrollment of 240 students) and two sessions in a computer studio lab (enrollment of 40-60 students). The faculty members in the course each teach all three sessions and a graduate teaching assistant is present in the computer studio lab classes as well. The large group meeting time provides the faculty members with the opportunity to provide students with an overview of the week's topics. The time in the labs is divided between assessments of student progress and applications and simulations of statistical concepts. The organizing center for the new course is a website developed by the Center for Academic Computing.

The Course Website

The course website serves as the technology gateway for the students in the course. By simply logging onto the site, students gain access to up-to-date administrative and assignment information. The site acts as a learning-centered syllabus (Diamond, 1998) by providing information and links to the web-based textbook, datasets, study guides, online quizzes, and additional resources. At the beginning of each week, students log on to the website and receive their weekly assignments which include readings and assignments (Figure 1). Students are responsible for completing any required readings before attending their large group meeting.

Figure 1: Online Course Syllabus



(Penn State Statistics Department, 2001, index.html)

Large Group Meetings

As mentioned above, the large group meeting takes place once a week. The main purpose of this session is to provide faculty with the opportunity to give an overview of the concepts covered in the assigned readings and to answer student questions. Despite the large enrollment, these sessions are mostly discussion-based and often include the use of short activities to further illustrate difficult concepts.

Computer Studio Labs

In the computer studio labs, students are divided into collaborative learning groups to enable more student-to-student interaction. In these labs, students are either assessed on the understanding of the pre-readings and assignments or they spend class time applying statistical concepts to real-world problems. The method employed to assess student preparedness and understanding of conceptual information is Readiness Assessment Tests (Michaelson, Black, & Fink, 1996). Students are expected to prepare outside of class by completing readings and homework assignments. Upon entering the lab session students individually take a Readiness Assessment Test (RAT). Immediately following the individual test, the students retake the test in their groups. The grades on the test are weighted with 2/3 of the final grade taken from the individual score and 1/3 of the final grade taken from the group score. The purpose of the RATs is to provide valuable formative feedback to both the students and the faculty member. Analysis of student answers can help faculty target their lectures and course assignments to clarify misconceptions and give additional practice.

As mentioned previously, the other function of the computer studio labs is to provide students with the opportunity to work on collaborative activities that enable them to apply statistical concepts to real-world problems. These activities (Figure 2) make use of either real-time data collected through the administration of surveys in the course or through pre-designed activities that make use of existing data sets (Figure 3).

Figure 2: Sample Activity

Activity #009: Moneybags

You are presented two bags that contain paper money (bills of varying denominations). Both bags contain 20 bills. The composition of each of the two bags--A and B-- is as follows:

Bag A	Denomination (x)	$1	$2	$5	$10	$20	$50
	Count of Bills	9	6	2	1	1	1

Bag B	Denomination (x)	$1	$2	$5	$10	$20	$50
	Count of Bills	1	1	1	4	6	7

Problem: One bill will be randomly picked from one of the bags. The identity of the bag is unknown to the person who draws. The person drawing the bill will receive $100 if he or she correctly identifies the bag from which it was picked; otherwise, receives nothing. The problem is to devise a strategy for guessing the bag.

First, let's rearrange the format of the denominations and counts for the two bags, as follows:

	Bag A		**Bag B**	
Denomination	Count	Proportion	Count	Proportion
$1	9	.45	1	.05
$2	6	.30	1	.05
$5	2	.10	1	.05
$10	1	.05	4	.20
$20	1	.05	6	.30
$50	1	.05	7	.35

(Penn State Statistics Department, 2001, Act009-rho.html)

While students are at work on these activities, faculty members and teaching assistants will interact with the groups and answer specific questions. If it appears that a majority of the class is having trouble applying a particular statistical concept, the faculty member will stop the entire class and conduct a mini-lesson to clarify student misconceptions.

Figure 3: Links to existing data sets

Datasets Listing

This is listed in reverse chronological order from the most recent week to the first week.

Week 4

1. Data for Activity 12 Survey 1

Week 3

No Items Found

Week 2

1. Data for Activity 10 Suvey 1

Week 1

1. Data for Activity 1 Survey 1

(Penn State Statistics Department, 2001, datasets.html)

Benefits of the Model

The new model capitalizes on the research showing the positive effects of active and collaborative learning strategies on student learning (Brandon & Hollingshead, 1999; Bonwell, 1996). Various active and collaborative learning methods have been shown to increase student mastery of material and their ability to transfer and apply new knowledge (Felder & Brent, 1996; Haller, Gallagher, Weldon, & Felder, 2000; Springer, Stanne & Donovan, 1999). By restructuring the class to allow for increased interaction between students and faculty and to give students the opportunity to become engaged in real-world problems and situations, it was hoped that the amount of student learning would increase. What follows is an explanation of the methods used to evaluate the project and the findings of the study.

METHODS

In order to assess the impact of the new delivery model on student learning, a pre- and post-content knowledge test was developed. This test was administered in Stat 200 at the beginning and end of each semester that the project was being funded as part of the Pew Grant. During spring 2000, a pre- and post-test control group design (Campbell & Stanley, 1963, p.8) was used to establish the extent to which there were differences in student outcomes between a pilot section (treatment group) of Stat 200 and a traditional section (control group). The results from the control group served as the baseline for comparison when the content test was administered to students during the full implementation semesters (fall 2000 and spring 2001).

RESULTS

Pre- and Post-Content Knowledge Test – Pilot Semester

In order to assess changes in student learning in Stat 200 and to establish a baseline for further study, a content knowledge test was administered at the beginning and end of the spring 2000 semester (pilot semester). Students in three sections took the pre-test and post-test: two sections were taught in the traditional three lecture, two recitation format (n = 340) and the other section was taught using the new delivery model of one lecture and two computer studio labs (n = 140). The performance in both the treatment and control sections of the course improved from pre-test to post-test. There was no significant difference between the two groups at the time of the pre-test and results indicated that both groups had approximately equal levels of pre-existing statistical knowledge. Even though this equivalence existed on the pre-test, the pilot group outperformed the traditional group on the post-test measure (66% correct in the pilot class, 60% correct in the traditional class). This difference in post-test performance between the pilot and traditional group was found to be statistically significant, $F(1,478) = 13.56$, $p < 0.001$[2].

A multivariate analysis of variance was used to analyze differences between student performance in the traditional class and the pilot class in the posttest measure. Four questions have been identified where the pilot classes outperformed the traditional section with a difference between 5%-10% (Table 1).

Table 1: Questions with 5-10% difference in performance between the traditional class and the pilot section of spring 2000

Question #	Concept	% Correct Traditional Class (n = 340) Spring 2000	% Correct Pilot Class (n=140) Spring 2000
1.	Median	75.9	81.4
2.	Percentiles	85.8	90.7
7.	Interpreting Results/ Proportions	86.8	91.4
8.	Confidence Intervals/ margin of Error	53.4	61.9

[2] Effect size = 0.176

However, these differences were not statistically significant. Judging from the percentages, the pilot section appears to have a larger portion of students who answered questions correctly on interpreting results and proportions, as well as understanding concepts such as median, percentiles, confidence intervals and margin of error.

Areas where the pilot group outperformed the traditional section with a difference greater than 10% included questions assessing student's ability to distinguish population versus sample data, interpret percentile and variability statistics as well as understand concepts such as mean, median, mode and the normal distribution (Table 2).

Table 2: Questions with more than 10% difference in performance between the traditional class and the pilot section of spring 2000

Question #	Content	% Correct Traditional Class (n=340) Spring 2000	% Correct Pilot Class (n =140) Spring 2000
6.***	Population versus sample	38.9	61.4
14.***	Percentiles/variability (range, standard deviation)	62.5	82.1
16.***	Distributions/Mean/ Median/Mode/Histogram	18.2	33.1
17.*	Mean/Trimmed mean/Median	50.8	63.3

*** significant mean difference at $p < 0.001$
* significant mean difference at $p < 0.05$

Additionally, one question was identified where the traditional class outperformed the pilot section with a difference of more than 5%. The traditional class had a larger proportion of students answer correctly the question assessing student's ability to read as well as utilize information from statistical tables. While 93% of the students in the traditional class answered this question correctly, only 85% of the students from the pilot class did. This difference was statistically significant, $p < .01$.

Pre- and Post-Content Test – Full Implementation

Because of the positive results from the pilot semester of the project, the traditional section was dropped beginning in fall 2000 and the new delivery methods were implemented across all sections of the course. Pre- and post-test results from the full implementation semesters (fall 2000 and spring 2001) were compared with the results from the spring 2000 traditional section. The purpose of the evaluations during fall 2000 and spring 2001 were to assess whether the learning gains achieved during the pilot semester would continue over subsequent semesters. If the result proved to be consistent then that would support the proposition that the results of the initial experiment could be generalized over time to future populations of students in Stat 200.

In fall 2000, all four sections of Stat 200 were taught using the new delivery model (n=681). Students in all four sections of the class took the content knowledge pre-test and post-test with performance in all sections improving from pre-test to post-test. On the pre-test students answered about 50% of the questions correctly with the post-test score increasing by more than 10%, to 68%. Spring 2001 results showed a similar increase from pre-test to post-test with the average score on the post-test of 67%.

When comparing the performance of students in the traditional class to those in the redesigned classes, the redesigned groups outperformed the traditional group on overall post-test performance (68% correct in the redesigned classes, 60% correct in the traditional class). This difference in post-test performance was found to be statistically significant, $F(1,1019) = 56.06$, $p<0.001$[3] for fall 2000 and $F(1,1114) = 57.69$, $p<0.001$[4] for spring 2001.

A multivariate analysis of variance was used to analyze differences between student performance in the traditional and the redesigned classes in the posttest measure. Two questions were identified where one or both of the redesigned classes outperformed the traditional section with a difference of between 5%-10% (Table 3). These differences

Table 3: Questions with 5-10% difference in performance between the redesigned classes of fall 2000 and spring 2001 and the traditional class of spring 2000

Question #	Concept	% Correct Traditional Class (n=340) Spring 2000	% Correct Redesigned Class (n = 681) Fall 2000	% Correct Redesigned Class (n = 776) Spring 2001
2.***	Percentiles	85.8	92.1	94.6
5.***	Opinion polls/Margin of error	82.6	(81.4)	89.9

*** Significant mean difference at $p < 0.001$

were statistically significant, $p < 0.001$. The redesigned sections had a large portion of students who answered questions correctly on the application of percentiles as well as understanding the concept of margin of error and problems addressing the use of opinion polls.

There were eight areas where the redesigned groups showed more than 10% increase in performance compared to the traditional group. These included questions assessing student's ability to use population and sample data, construct confidence

[3] Effect size = 0.223
[4] Effect size = 0.223

intervals and interpret margin of error information, understand the concept of dependent variables, standard error, reason about percentiles and standard deviations, conduct hypothesis testing and interpret statistical results as well as reason about means, trimmed means and medians (Table 4). The difference on posttest performance on all eight questions was statistically significant, $p < .001$.

Table 4: Questions with more than 10% difference in performance between the redesigned classes of fall 2000 and spring 2001 and the traditional class of spring 2000

Question #	Content	% Correct Traditional Class (n = 340) Spring 2000	% Correct Redesigned Class (n=681) Fall 2000	% Correct Redesigned Class (n = 776) Spring 2001
6.***	Population versus sample	38.9	53.5	52.3
8.***	Confidence intervals/ Margin of error	53.4	74.4	70.2
9.***	Sample size/standard error/Large sample	70.9	88.8	87.1
11.***	Variables (dependent)	77.0	85.8	88.5
14.***	Percentiles/Variability (range, standard deviation)	62.5	73.9	75.1
15.***	Hypothesis testing/Interpreting results/P-value/use of probability	45.4	58.1	62.1
16.***	Distributions/Mean/ Median/Mode/ Histogram	18.2	36.7	32.2
17.***	Mean/Trimmed Mean/Median	50.8	63.6	60.6

*** Significant mean difference at $p < 0.001$

DISCUSSION

Evaluation results of the new delivery model did produce significant learning gains across many statistical areas. However, there were some areas where student performance and content mastery was lower then predicted regardless of the delivery model being used. These areas included the ability to read and interpret information from tables, reasoning and solving problems involving the normal distribution, and interpreting data from histograms. Apparently, regardless of the class format these areas seem to be difficult for the majority of learners. Overall, the pilot and redesigned classes outperformed the traditional class on the post-content test. Students who took statistics under the new delivery method demonstrated a greater understanding of a number of statistical concepts. From these results, it appears that the new mode of instruction allows students to better learn and master statistical concepts covered in an introductory statistics class.

CONCLUDING COMMENTS

The transformation of elementary statistics to enhance student learning has proved to be a successful example for integrating technology with active and collaborative learning methods in post-secondary education. The gains in student learning caused by the new delivery model have had a tremendous impact on the statistics department at Penn State. Because of the success of this project, two additional introductory statistics courses are currently undergoing similar revisions. It is hoped that a replication of this study on those classes will show the gains in student learning.

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